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CW and Q-switched performance of a diode end-pumped Yb:YAG laser

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CW and Q-switched performance of a diode end-pumped Yb:YAG laser*
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Abstract

Using an end-pumped technology developed at LLNL we have demonstrated a Yb:YAG laser capable of delivering up to 434 W of CW power and 226 W of Q-switched power. In addition, we have frequency doubled the output to 515 nm using a dual crystal scheme to produce 76 W at 10 kHz in a 30 ns pulse length.

Key Words

Diode laser arrays, Rare earth lasers, Lasers in general

Introduction

Many potential applications motivate the development of efficient, compact 1 μm laser systems with operational lifetimes capable of exceeding thousands of hours. Yb-doped laser hosts offer spectroscopic and laser properties that make them promising candidates for high power 1 μm laser systems. In particular, Yb:YAG has a long storage lifetime 951 us and a very low quantum defect (8.6%) resulting in less heat generation during lasing than comparable Nd-based laser systems[1]. In addition, the broad pump line at 940 nm makes this material highly suitable for diode pumping using InGaAs diodes which are more robust than AlGaAs diodes which are used to excite Nd:YAG at approximately 808 nm. Recent results from lifetime tests on LLNL fabricated 940 nm diode packages have shown projected lifetimes of over 10,000 hours (with 30% degradation) when operated between 30-40 W per cm. Another advantage of using Yb:YAG occurs because the 940 nm absorption feature is approximately 10 times broader than the 808 nm absorption feature in Nd:YAG and therefore, the Yb:YAG system is less sensitive to the diode wavelength specifications.

Fig. 1 is a sketch of our end-pumped Yb:YAG laser. The pump source consisted of a 43 bar stack of 1 cm long InGaAs laser diode bars packaged on microchannel coolers. The diode light is first conditioned by a uniquely shaped microlens directly mounted on each diode package. The microlens allows the diode light to emerge with a far field 1/e divergence of ~10 mrad and ~150 mrad in the fast and slow axis directions respectively. The pump light is then homogenized and concentrated down with a fused silica lens duct to allow for end-pumping of the laser rod. The laser rod is a composite of doped and undoped YAG. The undoped YAG pieces or endcaps are diffusion bonded to both ends of the doped rod. The endcaps help reduce the thermal loading and stresses on the input and output faces of the rod and therefore help prevent damage. The Yb:YAG composite rod was coated at the pump end of the rod with a multilayered, dichroic coating for high reflectance at 1030 nm and high transmission at 940 nm, thus allowing one end of the rod to perform as a flat high reflector for the laser cavity. A simple broad band anti-reflection coating was

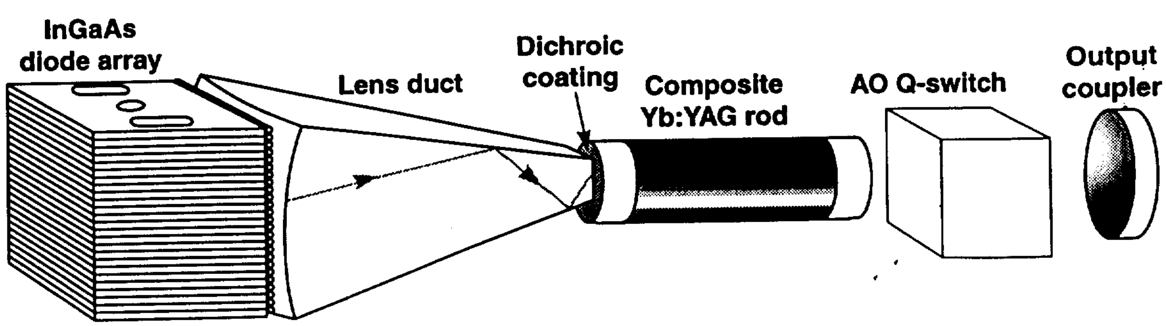

Figure 1. Schematic of the Yb:YAG laser system.

placed on the opposite or output end of the rod. An alternate design, which would allow for double pass pumping of the diode pump light, would require a conjugate dichroic coating placed on the output end of the rod. The conjugate coating would allow the pump light to be reflected and the laser light to be transmitted

Laser performance

We have demonstrated the Yb:YAG laser in both CW and Q-switched operation. The doping concentration was 0.5% and the rod diameter was 2 mm with an overall composite length of 60 mm. The rod was housed in a simple aluminum cooling jacket designed to flow coolant along the barrel of the rod. The rod temperature was kept close to zero degrees by using a mixture of water and propanol. Approximately 67% of the pump light was transmitted through the microlenses and lens duct. Subsequent designs have increased the efficiency up to 87%. Through internal reflections down the barrel of the rod, the pump light becomes well homogenized with approximately 75-80% of the pump light being absorbed on the first pass. In cw operation we produced up to 155 W cw power with an intrinsic optical to optical efficiency of 31%. The data and cw model are shown in Fig. 2. The model uses an analytical expression derived explicitly for the cw performance of quasi three-level systems[2]. The premature roll over seen in the data was due to several thermal issues. A redesign of the cooling housing and the use of a lower absorbing lens duct material at the pump wavelength were the primary modifications to help eliminate the thermal roll over. An 85% reflective output coupler with a 1 meter positive radius of curvature was used.

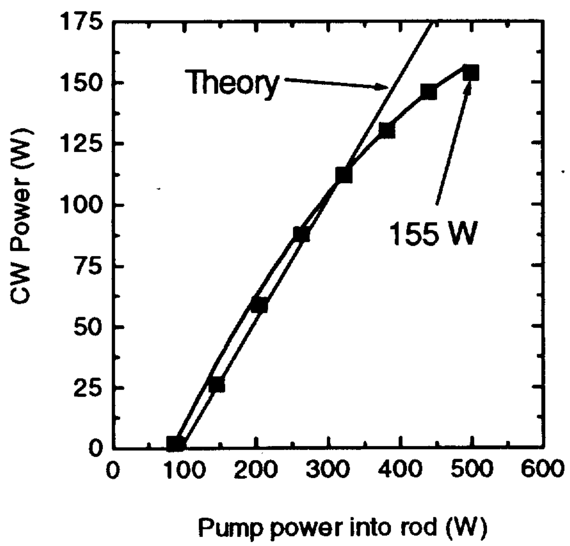

Figure 2. CW data and model for Yb:YAG.

The cavity length was approximately 15 cm. Measurements of the beam quality and a least squares fit to the data gave a $M_x^2 = M_y^2$ value of 9.

We also Q-switched output of the laser using an acousto-optic Q-switch. The insertion loss from the Q-switch was only 2%. We were able to produce up to 100 W at a repetition rate of 6.25 kHz resulting in a pulse energy of 15 mJ in a 60 ns pulse. The output coupler had a reflectivity of 70% and a 10 m positive radius of curvature. The measured beam quality of the Q-switched beam was $M_x^2 = M_y^2 = 4.9$. The theory and data are shown in Fig. 3. The model uses a transcendental expression specifically derived to address the performance of quasi-three-level Q-switched systems[3].

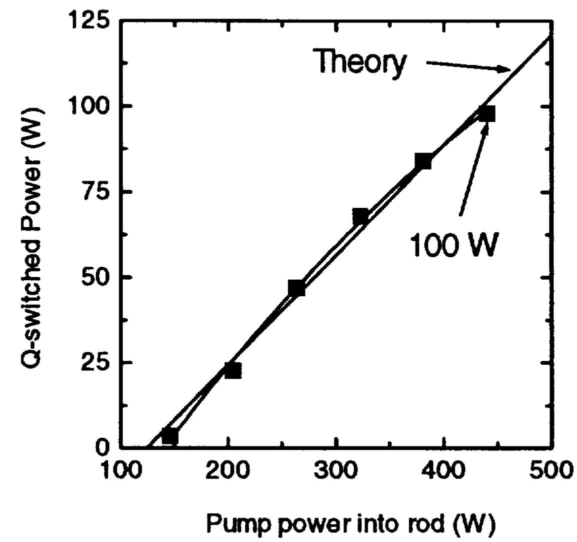

Figure 3. Q-switched data and model for Yb:YAG.

Thermal lensing and birefringence measurements

Measurements of the thermal lensing and of the stress induced birefringence are in close agreement with the quantum defect of 8.6% for Yb:YAG. A probe beam at 632 nm was used to measure the thermal lensing of the laser rod. As shown in Fig. 4, two different rods were used in the measurement. The best fit to the data yielded an average thermal efficiency factor of 10.2%, where thermal efficiency (η_{th}) is defined as the percent of pump power dissipated as heat into the rod. Measurements of the stress induced birefringence were made using a 1.03 μm probe beam. The best fit to the data results yielded a thermal efficiency factor of 8.74%. The average result from both types of measurements gives $\eta_{th} = 9.5\%$.

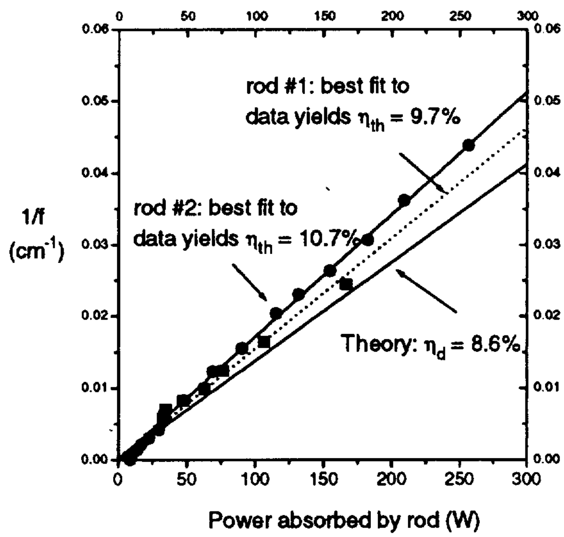

Figure 4. A plot of the inverse thermal focusing of the laser rod as a function of absorbed pump power.

Improved laser performance with large spot diodes

The experimental scheme shown in Fig. 1 was modified to incorporate an array of 1.5 cm long diodes with large spot optical cavities[4]. The 47 bar array produced up to 1733 W of cw power at 60 amps. In addition to the high powers available with the large spot diode structure (30-40 W/cm) the optical divergence is decreased due to the larger optical mode. The reduction in output divergence allows the microlenses to capture the diode light more efficiently. Employing the new diode array, the pump

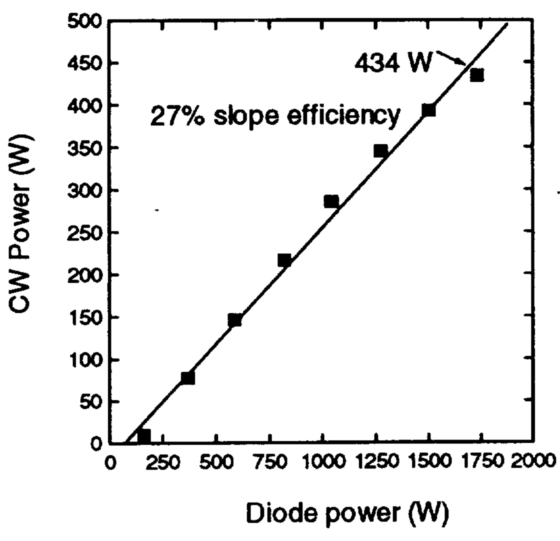

Figure 5. Up to 434 W of cw power was produced with the large spot diodes as the pump source.

delivery through the microlenses and lens duct increased from 67% to 87%. Using an 80% reflective, 1 meter positive radius of curvature output coupler, we produced up to 434 W of cw power. The optical-to-optical slope efficiency was 27%. In Q-switched operation using a more heavily doped (1%) Yb:YAG rod, we achieved up to 226 W at 10 kHz with a pulse length of 26 ns. Beam quality measurements were made at the 150 W level for both cw and Q-switched operation and yielded values of M^2 = 5 and 6.75 respectively.

Frequency conversion results

External frequency conversion experiments were conducted using Type II phase matching at room temperature with KTP. The phase matching angles were φ = 49.8 deg. and θ = 90 deg. The crystal sizes were both 6x6x8mm. To reduce the possibility of damage due to gray tracking mechanisms, the frequency converted light generated from the first crystal was split out of the 1.03 μm path with a dichroic beam splitter. Using two KTP crystals and a dichroic beam splitter we achieved up to 40% conversion. With 217 W of 1.03 μm input power up to 76 W of cw power at 515 nm was produced in a 30 ns pulse length.

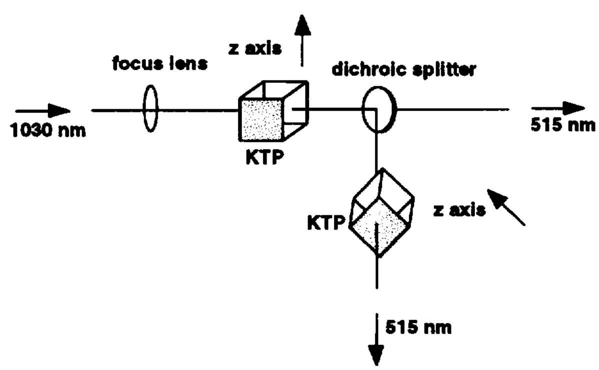

Fig. 6 A dual crystal conversion scheme was employed using KTP.

Summary

We have produced up to 434 W of cw power at 1030 nm with an end-pumped Yb:YAG laser. At 10 kHz repetition rates we produced up to 226 W of Q-switched power in a 26 ns pulse length. The M^2 values at 150 W cw and Q-switched were 5 and 6.75 respectively. Using a dual KTP crystal frequency conversion scheme, we produced up to 76 W of 515 nm light in a 30 ns pulse length. The use of large spot diodes in our system enabled us to reach diode pump powers of up to 1733 kW at 941 nm.

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